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CONSTRUCTION OF AN AUTOMATED FIBER PIGTAILING MACHINE FOR OPTOELECTRONIC COMPONENTS

Uniphase Telecommunications Products

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CONSTRUCTION OF AN AUTOMATED FIBER PIGTAILING MACHINE FOR OPTOELECTRONIC COMPONENTS

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13. ABSTRACT *(Maximum 200 words)*

The purpose of this program was to design and evaluate a low cost Automated Fiber Pigtailing Machine (AFPM). The pigtailing process attaches fibers to optoelectronic devices with submicron alignment accuracy. The process is labor intensive and costly; thus the goal of the program is to replace the operator with an automated machine in order to reduce cost and increase the output. An AFPM was designed, fabricated and delivered to Uniphase Telecommunications Products (UTP) and Ortel and production feasibility demonstrations were conducted. There were some initial problems; this is expected with a new process and machine. With improvements, such as enlarging the field of view of the vision system for fiber alignment, improvement in epoxy dispenser mounting, etc., the AFPM has a lot of potential to serve as a valuable asset to an assembly process. It is possible for the AFPM to repay itself in approximately 6 months when it's met system and component reliability. Thus machine commercialization requires further development of the prototype to provide a robust and reliable platform for production environments. The AFPM at UTP has been transferred to the IFOG Manufacturability (MANTECH) program sponsored by the U. S. Army Missile Command (MICOM) for further improvements and demonstration to insure commercial production feasibility.

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1.0 EXECUTIVE SUMMARY

This purpose of this program was to design and evaluate a low cost Automated Fiber Pigtailing Machine (AFPM). Massachusetts Institute of Technology Manufacturing Institute and Lawrence Livermore National Labs (LLNL) make up the design team, Uniphase Telecommunications Products (UTP) and Ortel represent the industrial end-user of an AFPM, and Newport represents a commercial vendor that could potentially offer the AFPM as a commercial product.

The program addresses automation of the pigtailing process. The pigtailing process attaches fibers to optoelectonic devices with submicron alignment accuracy. The process is labor intensive and costly; the goal of the program is to replace the operator with an automated machine in order to reduce cost and increase throughput.

This report is intended to summarize the evaluation of the AFPM. An AFPM was delivered to UTP and Ortel, and feasibility production demonstrations were completed. Results of the demonstrations are included with feedback from both end users (UTP's results are included in the main body, Ortel's results are included in Appendix A). Evaluations of the machine and plans for commercialization are included from Newport (Appendix B). Information regarding the design of the AFPM will be published by Lawrence Livermore National Labs.

2.0 DESCRIPTION OF PRODUCTION FEASIBILITY DEMONSTRATION AT UTP

The production feasibility demonstration was conducted in order to show that the AFPM could work in a manufacturing environment. The process steps for the AFPM were noted and a chronological account of the demonstration was kept.

2.1 Description of Process Steps

During the production feasibility demonstration, process steps were refined to remove unnecessary steps, add unforeseen steps, and modify existing steps. The process steps listed below accurately represent process steps in their final state.

PROCESS STEPS

1. Operator winds fibers on spools.
2. Operator strips and cleaves fiber leads.
3. Operator loads stripped and cleaved fiber leads on kit tray.
4. Operator cleans tray by air blowing and wiping clean the tray.
5. Operator loads optical chip onto kit tray.
6. Operator cleans optical chip and fibers.
7. Operator loads kit tray onto a pallet.
8. Operator places pallet on the transport mechanism.
9. Pallet is indexed until the kit tray is in pigtailing position and is registered in place.
10. Light is launched into the input fiber.
11. Input manipulator picks up input fiber lead.
12. The input fiber lead is then transported to the epoxy dispensing system and epoxy is dispensed onto the fiber carrier block end face.
13. The input fiber lead is transported to the chip input location.
14. Output manipulator brings large-core diameter multimode fiber lead to chip output position.

15. Using the vision camera display and minimal operator assist, both fibers are jogged with the computer's keyboard to a position where it is possible that some initial level of light will go through the chip in the next step.

16. The input fiber is moved through a two dimensional scan pattern until some initial level of light goes through the chip and into the output fiber.

17. The input fiber lead is moved in a hill-climbing fashion to maximize light coupling, while the operator jogs it forward to the cure location.

18. While light coupling in the input side is maximized, the curing lamp is turned on to cure the epoxy.

19. The input manipulator releases the fiber and returns to the start position.

20. The output manipulator picks up the output fiber lead

21. The output fiber lead is then transported to the epoxy dispensing system and epoxy is dispensed onto fiber carrier block end face.

22. The output fiber lead is then transported to the chip output location.

23. Using the vision camera display and minimal operator assist, the location of the output fiber lead is fine tuned by jogging the output manipulator using the computer's keyboard.

24. The output fiber is moved through a two dimensional scan pattern until some initial level of light goes through the chip and into the output fiber.

25. The output fiber lead is moved in a hill-climbing fashion to maximize light coupling, while the operator jogs it forward to the cure location.

26. While light coupling in the output side is maximized, the curing lamp is turned on to cure the epoxy.

27. The output manipulator releases the fiber and is returned to the start position.

28. The kit tray is unregistered and the operator removes the pallet from the transport mechanism.

29. Operator removes kit tray from pallet.

30. The process is repeated for the second output except for steps 1 - 19.

2.2 Chronological Description

Prior to the production demonstration a tray selection was completed. The selection was necessary because the camera's focal depth did not compensate for tolerances within the kit tray and locating pistons, the field of view did not

always include the fiducials on the chip, and increased loss can be attributed to angular tolerances within the kit tray and locating pistons. Twelve trays of the thirty manufactured were selected for use during the production feasibility demonstration.

Upon completion of the tray selection, practice chips were pigtailed. There were no problems with epoxy bridges as anticipated. (Prior to this test there was concern that the distance between the center of the waveguides would not be large enough to accommodate all carrier blocks without the existence of an epoxy bridge. This was due to a foreseen problem with the existing mask.) Therefore the demonstration began under the impression that all chips would be pigtailed to include two outputs.

As the demo began, each device was tested for loss and extinction ratios directly after it came off the machine. The first device was very lossy, therefore a few adjustments were made and the next chip was pigtailed. The second device tested much better than the first, but not to our satisfaction. Therefore a third chip was tested before any additional adjustments were made. The third chip performed worse than the second.

At this point, the devices were brought through the post pigtail process and tested afterwards. They still performed poorly. At this point, the third device was investigated for visual defects at the pigtails. This chip showed angular problems in pitch, yaw, and roll. The AFPM was then adjusted specifically for these angles and the 4th device was pigtailed. As the second output was pigtailed, a noticeable yaw angular misalignment was observed. This misalignment was not observed on the first output. Therefore the pigtail was not tacked on and the problem was investigated further.

After investigating the angular problem, it was observed that the vacuum chuck held the two output fibers a degree from parallelism. LLNL was notified of the problem, however they could not render a solution for the production feasibility demonstration. Therefore, an alternate plan was developed.

With this problem, it is possible to pigtail the first output, and then adjust the chuck for the second output. However, completing this task for every device is very costly since paths need to be replanned for every chuck adjustment. The next alternative is to pigtail the input and first output of every device, and then adjust the chuck for the second output. This alternative requires that the pigtailed chip remain on the tray while awaiting the second output and any post processing must be completed on the tray. Minor adjustments were made to the post processing to accommodate this.

The last detail was that only twelve trays had been chosen for the production feasibility demonstration. Time needed to adjust the vacuum chuck and replan the paths is not trivial. Therefore, only the last twelve devices pigtailed would

remain on trays, and await the second output. The production feasibility demo continued with minor problems with the epoxy, block pickup, dust, and source coupler problems.

The 19th device was the first device to remain on a tray through post processing. After the 30th device was pigtailed, the vacuum chuck was adjusted, paths were planned, and the second outputs were pigtailed. The epoxy bridge was a problem on very few devices, and it never prohibited attaching the second block. All of the devices with two outputs and three of devices with single outputs were submounted.

3.0 DESCRIPTION OF TESTING AT UTP

3.1 Testing Flow

A test plan was developed for the production feasibility demonstration. This plan is shown in a flow chart in Figure 1. This plan assumed that both outputs would be pigtailed.

A new plan for test flow was developed when the angular problem with the vacuum chuck was identified. This plan is shown in a flow chart in Figure 2.

3.2 Standard Tests

UTP has tested the devices for loss, split ratio, and polarization crosstalk. UTP has completed these tests in the same manner as standard product. These tests were completed at pigtail, after post processing, and after environmental testing.

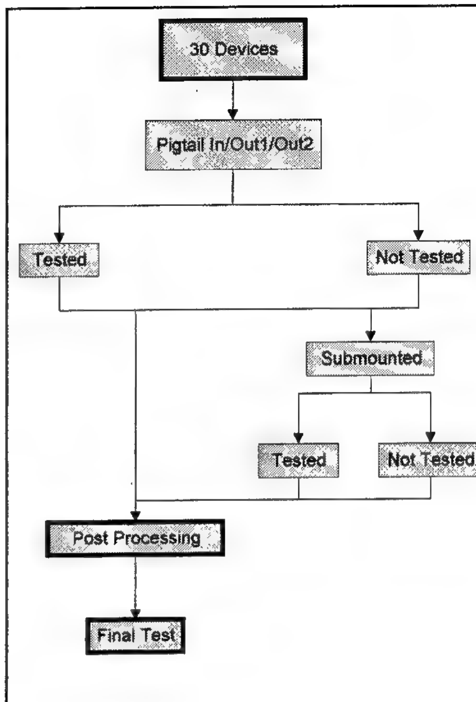

Figure 1: Planned Test Flow

3.3 Environmental Test

The environmental test consisted of 100 temperature cycles from -65C to +125C at 1C per minute ramp rate.

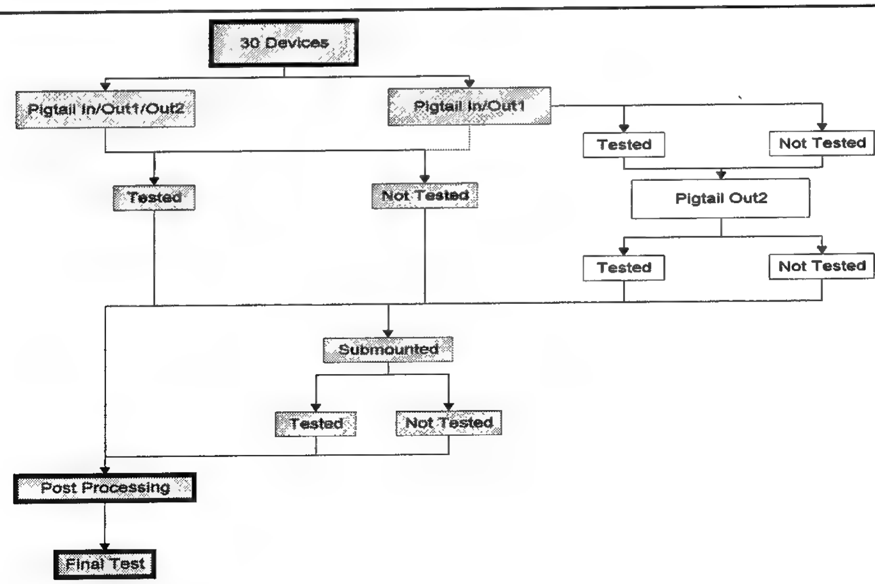

Figure 2: Modified Test Flow

3.4 Time

Timing data was taken to characterize the process. Times were taken on loading the kit tray and pigtailing the device. These times were taken by noting the time the operator started and ended the procedure.

3.4 Standard Specifications

The significant specifications related to the pigtailing process for the 830nm FOG are shown in Table 1.

Table 1: Specifications for 830nm FOG IOC

Parameter	Guaranteed	Units
Insertion Loss (pigtailed)	5.0	dB
Split Ratio (pigtailed)	45/55 to 55/45	%
Polarization crosstalk (fiber)	-24	dB

4.0 SUMMARY OF TEST RESULTS FROM UTP

4.1 Loss

A chronological chart of the losses for each device is shown in Figure 3 on page 10. Only three of the thirty devices failed the loss test. Two of the devices that are tagged NO DATA had bad wafer level test data, the other two devices were broken during processing. It is very important to notice that only one chip failed grossly (it was the very first pigtailed chip). The losses improved significantly as the production feasibility demonstration progressed.

A summary of the loss data is shown in a histogram in Figure 4 on page 11. The histogram shows that most of the devices perform with losses better than 3dB.

A comparison of the wafer level loss data and after pigtail loss data is shown in Figure 5 on page 12. Devices such as #7 and #15 show that the AFPM can produce devices with better losses than the loss measured at wafer level. Wafer level test is completed with different equipment which sometimes provides data showing higher losses than what is achievable with pigtailing.

4.2 Split

The split ratio results are shown in Figure 6 on page 13. During the production feasibility demonstration, split ratios were not actively monitored during pigtailing on the AFPM. Therefore it is important to notice that at the end of the demonstration, the split ratios were within specification without active monitoring.

4.3 Polarization Crosstalk

A summary of the polarization crosstalk is shown in a histogram in Figure 7 on page 14. There are a significant number of devices that are falling out of specification. This leads us to the conclusion that fixturing of the fiber in the roll axis is not adequate for pigtailing in order to achieve extinctions of better than -20dB.

4.4 Environmental

Upon completion of the environmental testing, five of the devices were tested. A loss comparison of *At Pigtail*, *After Post Processing*, and *After Environmental Test* data is shown in Figure 8 on page 15. None of the devices failed after the environmental testing. There is also a comparison that shows the unsubmounted parts performing better than submounted parts after the environmental testing. This result is interesting, however, the sample size is to small to formulate general conclusions regarding the use of submounts.

A polarization crosstalk comparison is shown in Figure 9 on page 16. The comparison shows an improvement in crosstalk on all but one fiber.

4.5 Timing Data

The average time for loading the kit tray was 10min per fiber, so 30min per device (assuming device has 1 input and 2 outputs). This time is significantly high due to the fact that the kit trays were not loaded as they had been intended due to technical difficulties with the kit tray/vacuum chuck interface.

The average time for pigtailing was 11min 17s per fiber, so 33min 57s per device (assuming device has 1 input and 2 outputs). The best time achieved for pigtailing was 4min per fiber, only 1min shy of the 3min goal time.

At first glance the averages appear much worse than expected, however one must consider that this was the first time this machine was run, and a machine is never bug free when it is first run. The best numbers show that there is significant potential for enhancements to improve the averages.

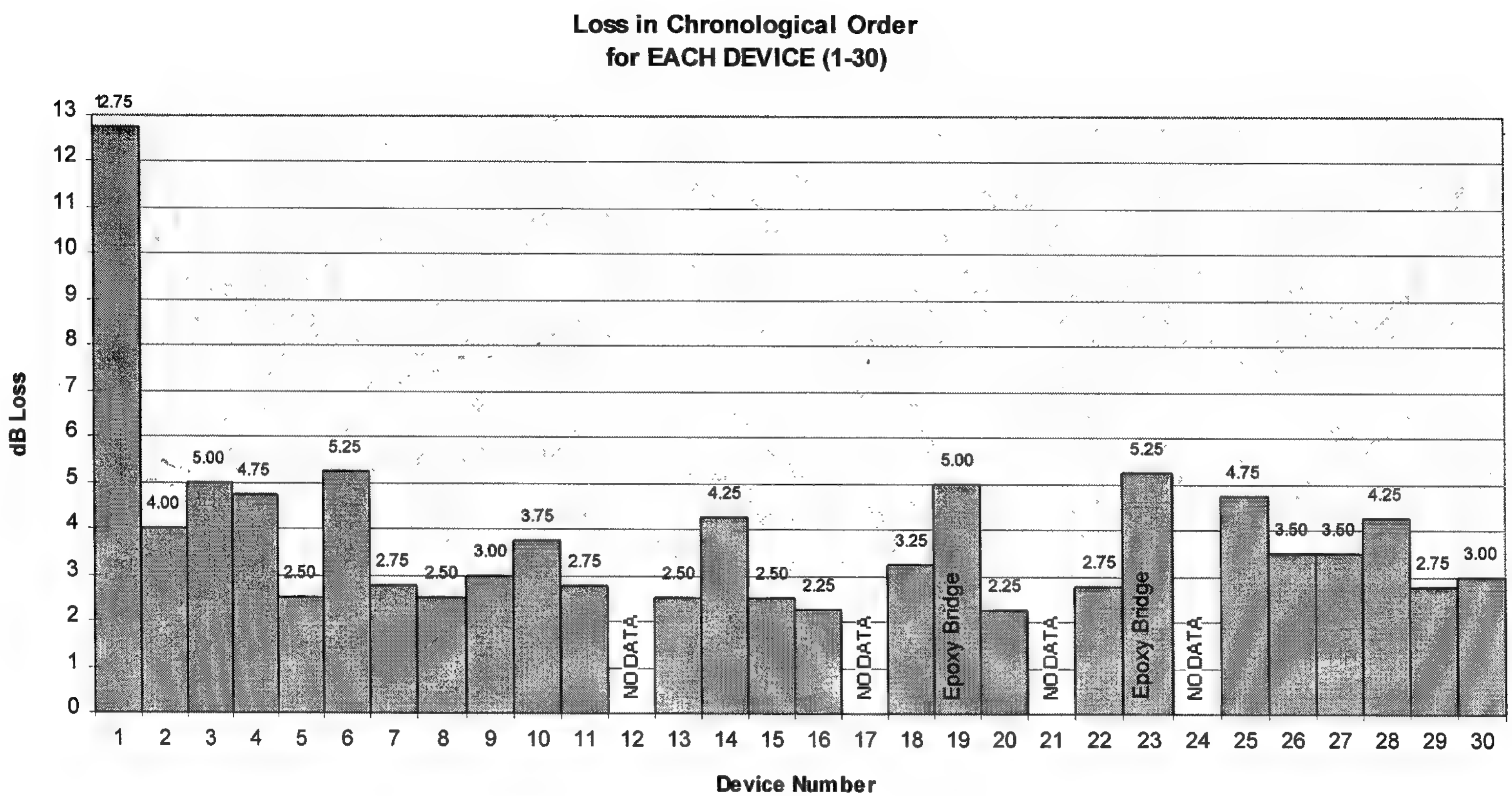

Figure 3: Loss in Chronological Order

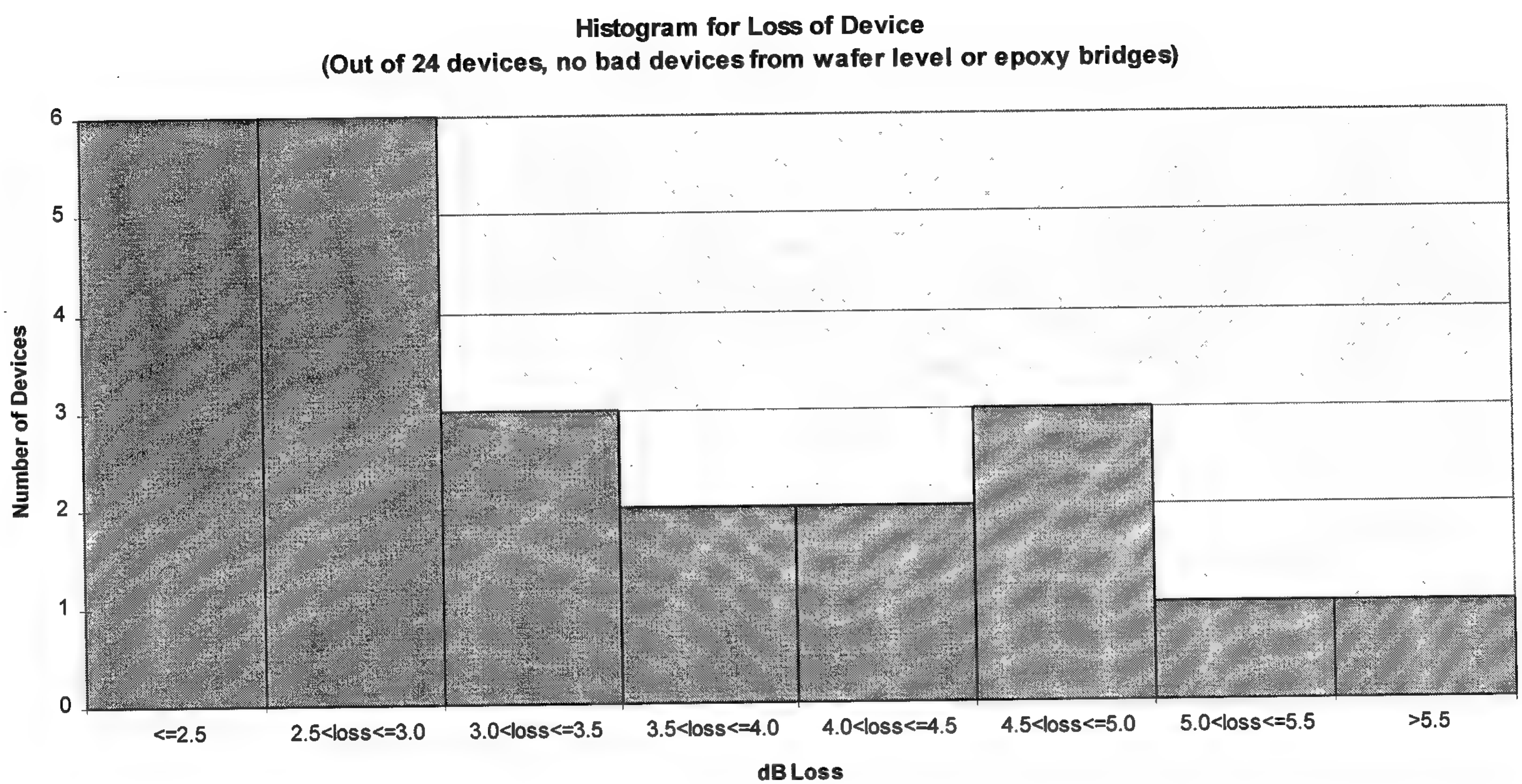

Figure 4: Histogram for Loss of Device

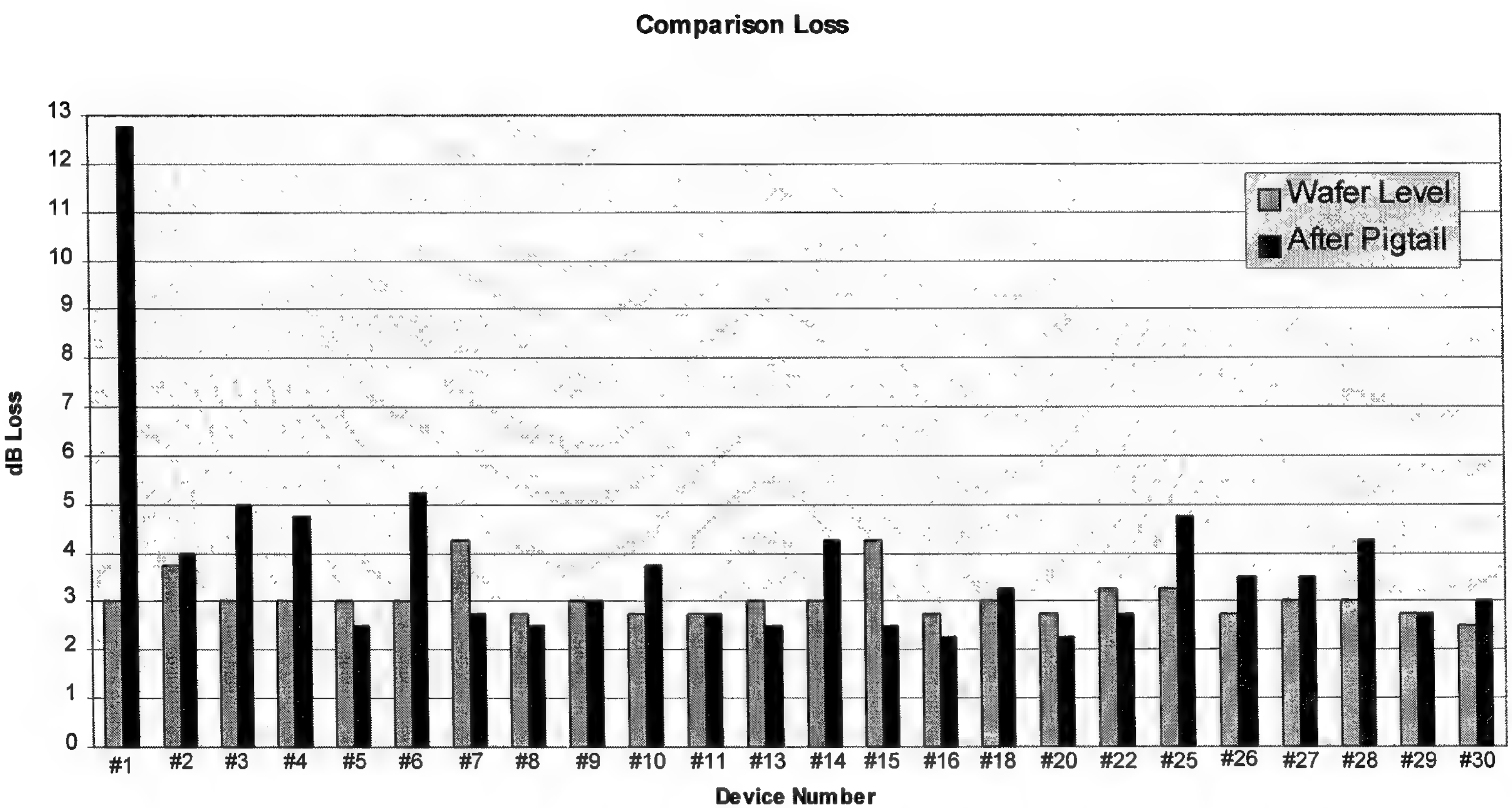

Figure 5: Comparison Loss

Chronological Split Ratio
(not including bad devices from wafer level or devices with epoxy bridges)

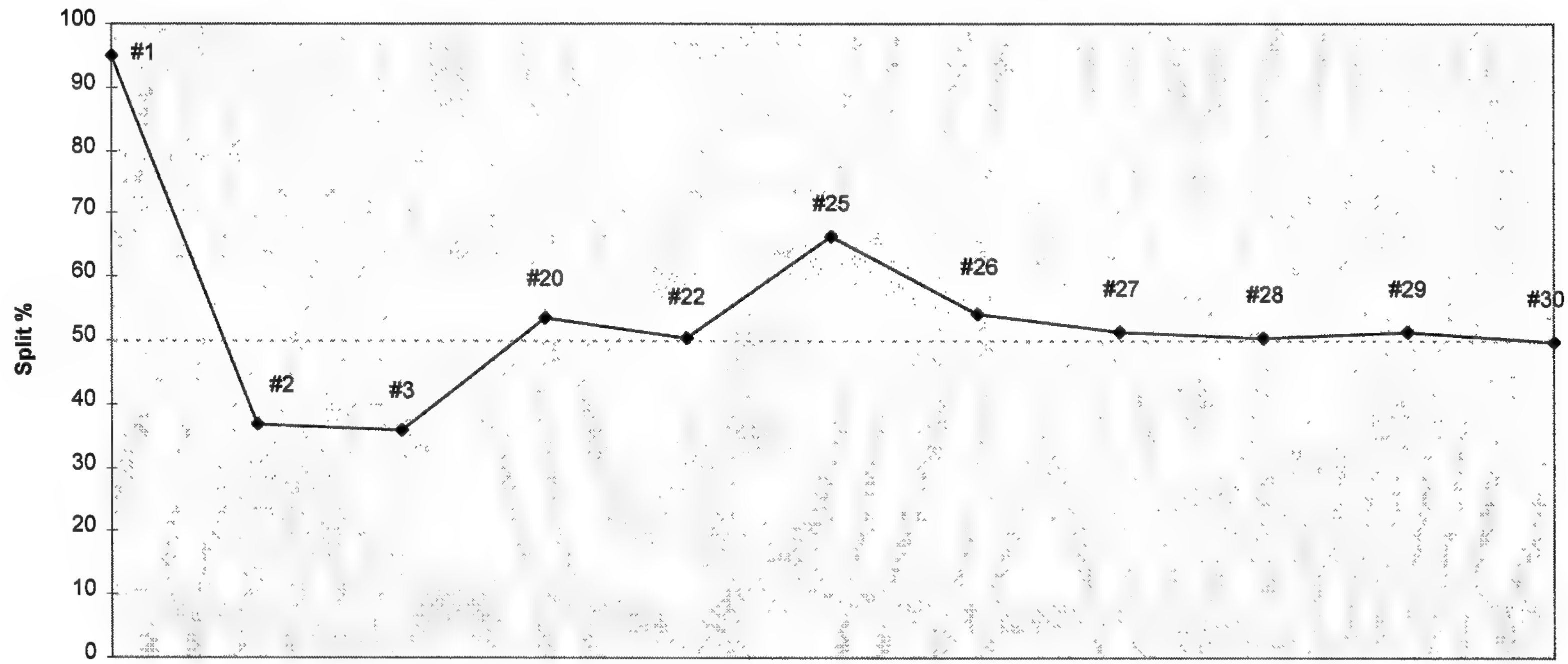

Figure 6: Chronological Split Ratio

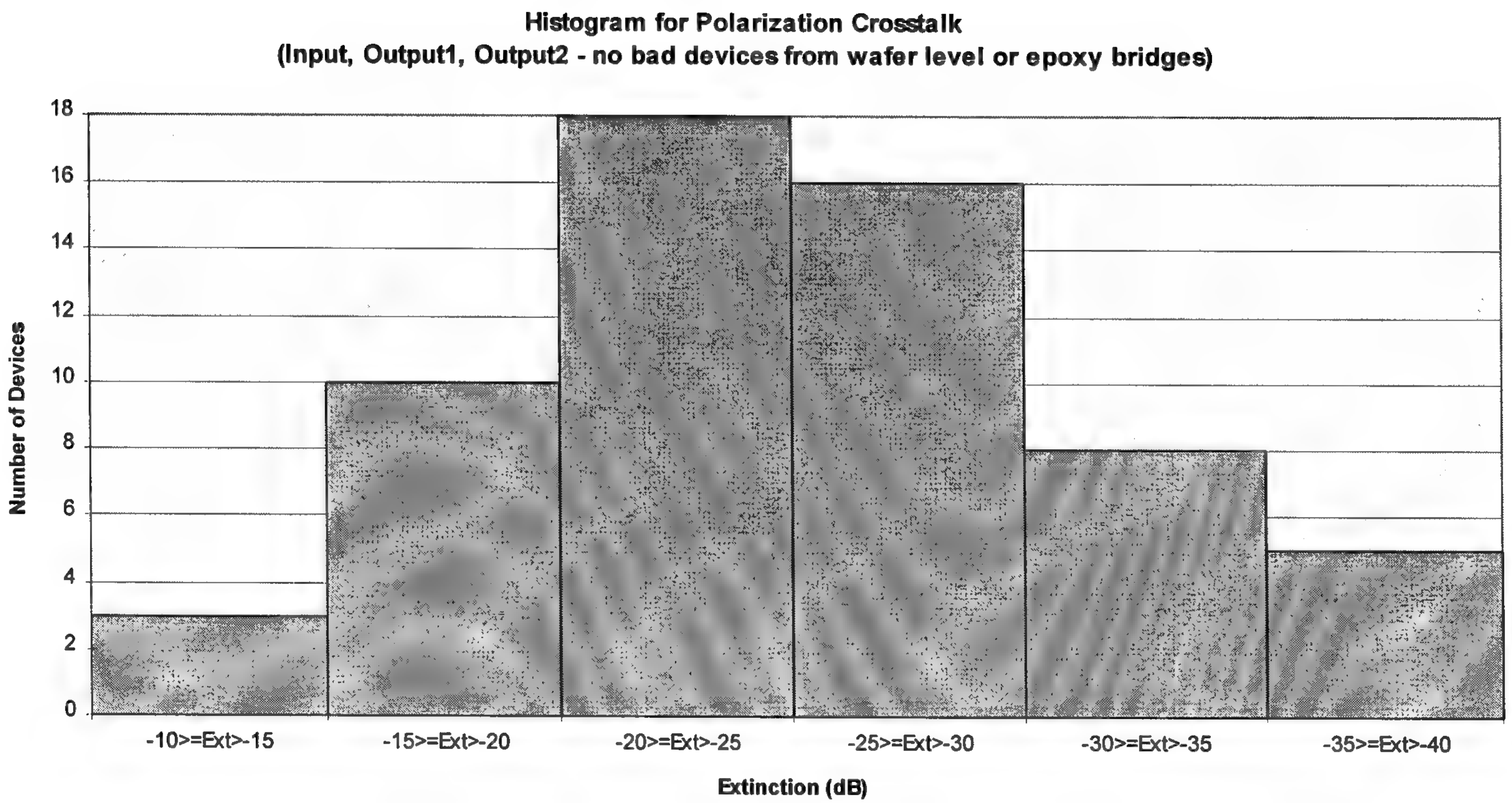

Figure 7: Histogram for Polarization Crosstalk

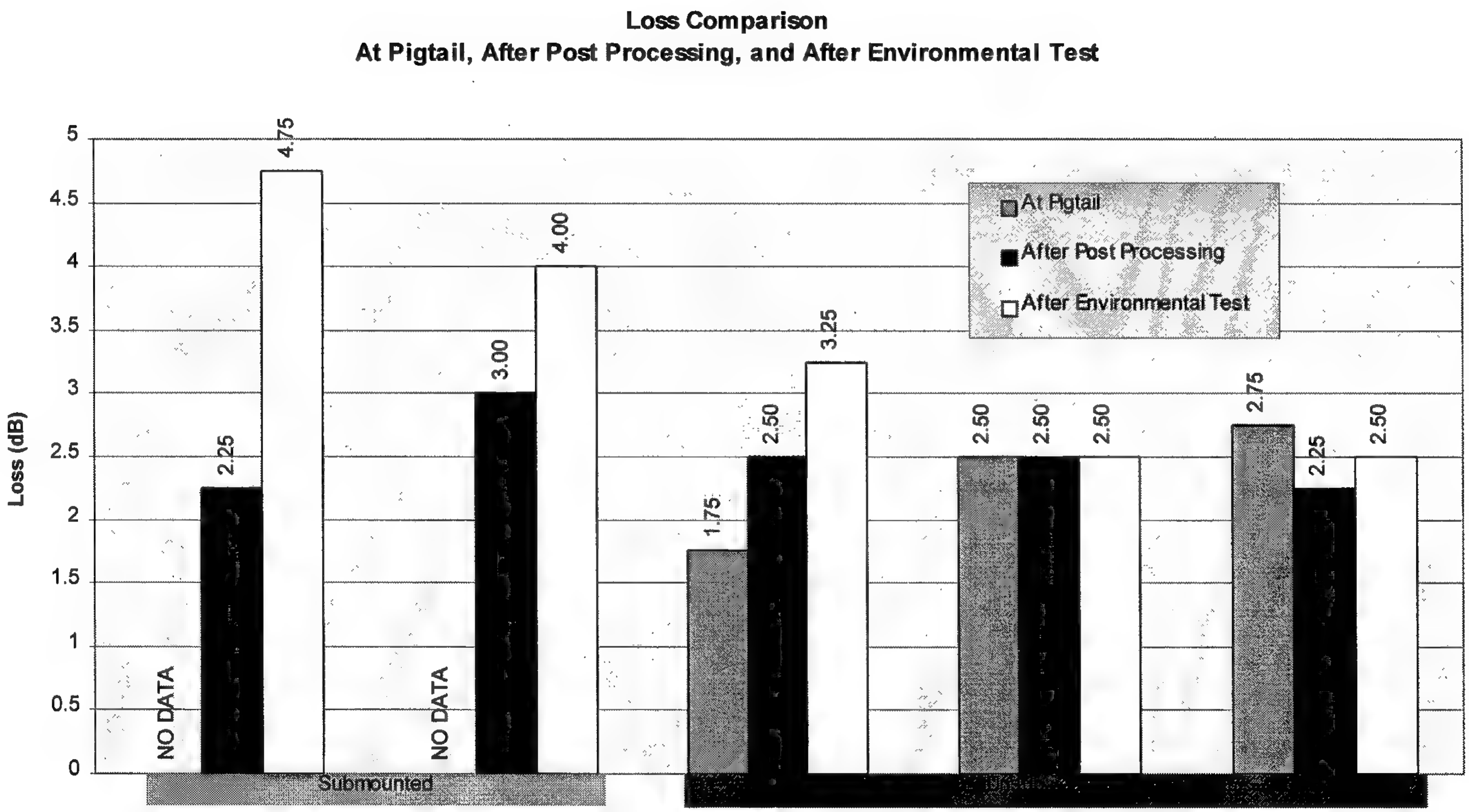

Figure 8: Loss Comparison with Environmental

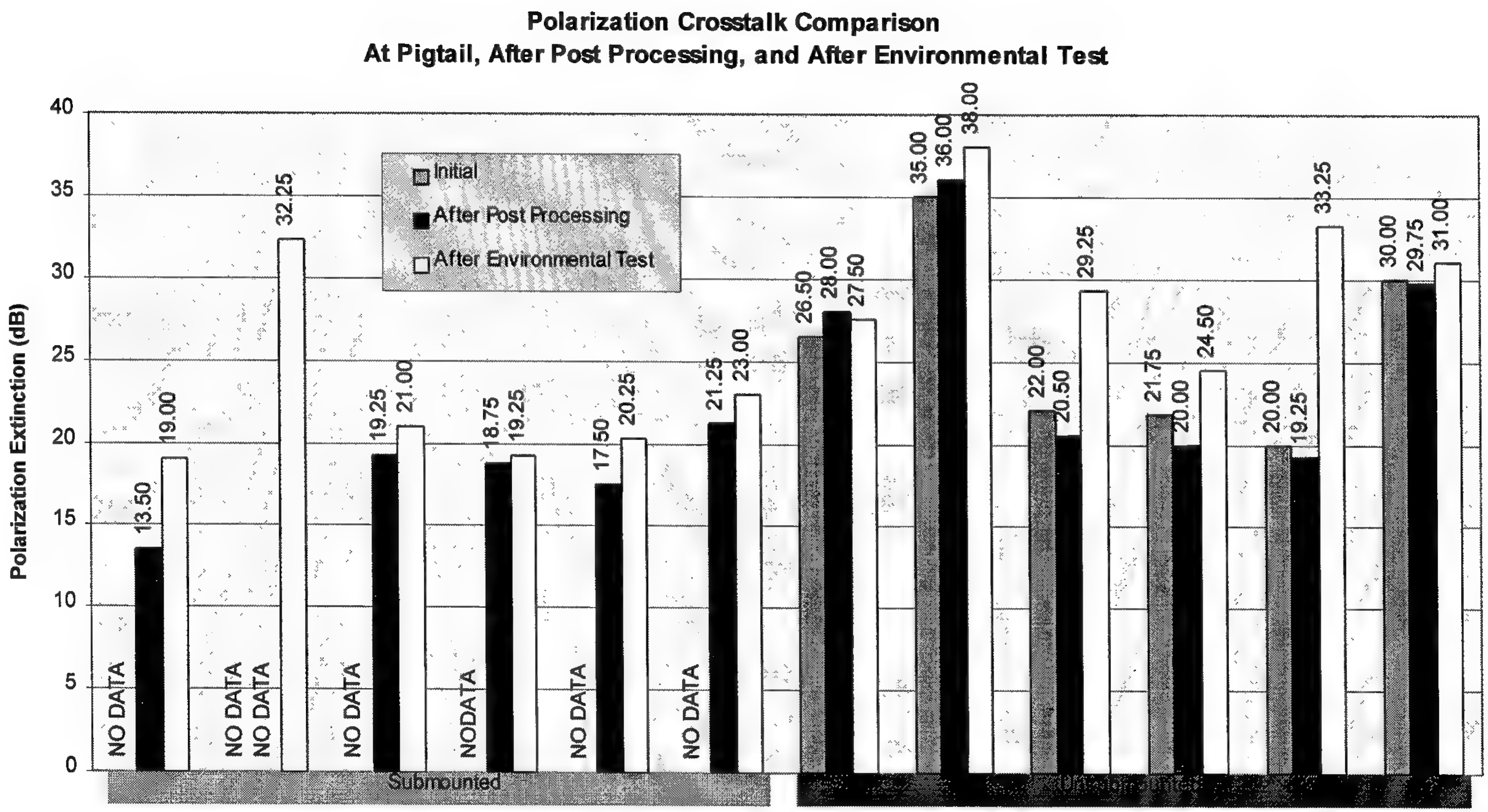

Figure 9: Polarization Crosstalk Comparison with Environmental

5.0 LESSONS LEARNED

With the development of any new machine, many technical lessons can be learned and improved upon. The AFPM has a series of lessons learned associated with it. The lessons listed here have been formulated by UTP and MIT Manufacturing Institute. These lessons are associated with the AFPM at UTP.

Vacuum Chuck

The vacuum chucks used on the AFPM are not adequate for manipulating fibers. These chucks frequently have problems picking up the blocks, holding onto the blocks, and fixturing the blocks angularly. These chucks also require that high tolerances on the fiber carrier blocks.

Epoxy Dispensing

Accurate epoxy dispensing is critical. Throughout the production feasibility demonstration, the epoxy dispensing system performed poorly. It was not repeatable and it frequently would not dispense any epoxy. This type of behavior is unacceptable in an automated environment. The amount of epoxy dispensed is critical because to much will lead to epoxy bridges and to little will lead to an insufficient bond line.

Kit Tray

UTP has used the kit trays in a way that was not intended. This has driven the time to load a kit tray to unacceptable amount for manufacturing. The trays were loaded this way to minimize issues with fiber manipulation and the fixturing of the roll axis.

Dust Particles

Dust particles are a concern in manufacturing, an operator will notice dust during manual pigtailing, and remove it. The AFPM does not have a system to control the dust, a method for removing dust, or a method for noticing dust.

Source Coupler

The source coupler mechanism launches light into the input fiber. The system can accurately launch light if the fibers were located accurately. However, loading the fibers accurately is a difficult task and often results in broken fibers from collisions. The splice can also become dirty from use, resulting in low light coupling.

Light Source

A predictable light source is beneficial for the AFPM. The AFPM can pigtail with the current unstable light source, however, it is difficult to determine the value of the chip that is being pigtailed. A predictable light source would allow the AFPM to give rough estimates on loss values.

Camera Transportation System

The existing camera transportation system has a linear motion produced from a piston. This motion is very rough. The camera does not include autofocus or automated adjustments for it's field of view. The addition these items would provide a more robust system that would not rely on the tolerances of other modules when using a vision system.

Polarization Alignment

Polarization alignment through fixturing is not adequate for high performance devices.

6.0 RECOMMENDATIONS

A summary of recommendations for the FOG and Commercial Modulator applications is shown in Table 2. This table is intended to summarize what actions would be taken from the lessons learned for each case.

Table 2: Recommendations for Commercial Applications

Recommendation	*FOG Application*	*Commercial Modulator Application*
Modify and Improve Vacuum Chuck System	Yes	Yes
Improve Epoxy Dispensing System	Yes	Yes
Modify and Improve Kit Tray for different devices	Yes	Yes
Environmental Control System	Yes	Yes
Active Light Throughput System including modifications to Source Coupler (Light Launch)	Yes	Yes
Modify and Improve Camera Transportation System	Yes	Yes
Stable Light Source	Yes	Yes
Active Polarization Alignment Module	Yes	No
Voltage Application System	No	Yes

8.0 CONCLUSION

Although the AFPM requires some improvement, the machine has demonstrated great potential for the cost reduction of pigtailing. The machine can increase throughput, while relieving an operator of the tedious pigtailing task. Therefore the need for highly skilled labor is eliminated. At the same time, improved process control is achieved since the operator is performing less tasks. The machine could include error detection, allowing the operator to attend to other tasks.

The success of this program is evident from the results of the production demonstrations. The cost of pigtailing can be significantly reduced with the integration of the AFPM into manufacturing. The low cost design of the machine ensures that the AFPM can pay for itself in a relatively short amount of time.

APPENDIX A - ORTEL REPORT

AFPM PROGRAM

P.O. #001924-00

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Final Version

Submitted to: Uniphase Telecommunications Products
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September 25, 1996

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AFPM Final Report
September 13, 1996

Introduction

The method to couple photodiode or laser pigtail devices normally entails a manual process and typically takes a highly-skilled operator. Attaching a fiber to a photodiode or laser device can take up to one half hour of labor time which could comprise a large portion of the overall cost of a pigtailed photodiode or laser module. The development of an automated fiber pigtailing machine can significantly reduce the coupling time, thus reducing the manufacturing cost of a photodiode or laser module. Since high precision is needed to couple a photodiode or laser device, an automated pigtailing machine also provides a precise method of attachment. Expected labor savings of a coupling process with an automatic fiber pigtail machine can be as much as 33% as compared to a manual process. Ortel decided to have a machine designed for photodiode coupling because of the high volume and low cost requirements of photodiode modules. Also, because of the relaxed tolerances associated with photodiode alignment relative to a laser, the design of the machine was a bit easier.

AFPM Specifications

The Automatic Fiber Pigtailing Machine (AFPM) is capable of adapting to Ortel's current photodiode package design. This was the intention when the specifications were developed by the design team. The design team decided on three degrees of freedom to align the fiber to a photodiode. The range and resolution of the fine aligner were specified to be 25um and 0.1um, respectively. However, the 'Z' motion was specified to have a resolution of 0.5um because of the looser tolerance in the 'Z' direction. The coarse aligner was spec'd to have a range of 25mm. The AFPM was designed to include a parts tray that would allow simple and fast replacement of multiple devices and fibers. The vision system was essential in providing the coarse alignment in order to start the fine

alignment with the fiber in the correct location each time. The process time was a key in determining the AFPM capability. The design team set a goal of 3 minutes per device to achieve a throughput of 20 devices per hour. A complete specification was developed and can be provided.

Modification of Ortel's Process

Ortel developed a new coupling procedure that would adapt to the AFPM. The new process includes using a blue light epoxy as the attachment method. The blue light epoxy allows the epoxy to cure at blue light wavelengths making it safer to the operator than a UV cure epoxy. Ortel's old attachment method was a thermal cure epoxy which would have made the AFPM design more difficult and would not allow the process to meet the design goal of three minutes per each device. The new process consist of applying one large spot of blue light epoxy over the fiber to secure it in place. Blue light epoxy can cure in 60 seconds with the proper light source, making the cure time very short. A disadvantage of the blue light epoxy is that it cures partially with room light making the pot life of the epoxy very short if not protected from room light.

Ortel also decided to eliminate fiber roll during the coupling process to reduce the complexity of the machine. Normally, by rotating the fiber upon its axis, the optical return loss can be adjusted to conform to specification. By experimentation, Ortel verified the optical return loss was consistent if the fiber angle was in the same position each time. As part of the kit tray loading the operator will verify the correct position of the fiber angle when inserting the fiber. Also, Ortel elected not to measure optical return loss during the coupling process which is normally done, but will measure it off line after the coupling process.

The Design Cycle

The design team met several times during the course of the development cycle to provide status updates and get inputs from the other team members. The early successes were partially due to the fact that a complete specification was developed at the very beginning of the

program before any major work took place. This allowed the whole team to know what to expect of the AFPM. Ortel provided valuable input during the design cycle. The design reviews were essential to establishing the conformance of the machine. Minor schedule delays occurred at the end of the program, however, considering the 2000 miles or more separation of the team members, the project went remarkably well.

Production Demo

The AFPM machined arrived at Ortel on February 22, 1996 and the set-up was performed by LLNL. The set-up went fairly well and took only a few hours before we were able to turn the machine on. LLNL and Ortel attempted to run a few parts through the machine but a few obstacles were encountered. First, it was determined that Ortel photodiode chips could appear 'bright' or 'dark' depending on the viewing angle. This confused the imaging algorithm. LLNL succeeded in changing the imaging code to accept both a 'bright' or 'dark' photodiode chip. Second, several of Ortel's photodiodes were out of the field of view for the vision system. Pre-screening of the photodiode modules had to be done to find the best placement of the photodiodes. Ortel will have to modify its current photodiode placement to align the photodiode more accurately or, alternatively, the field of view needs to be enlarged. Once the set-up of the machine was completed and the major bugs were worked out, the production demo took place.

The production demo goal was to pigtail 30 units without human involvement. Some difficulties were encountered, which is to be expected with a radically new process. Most of the 30 units had to be coupled in the manual mode of the software, which allowed us to proceed with each step of the process. We were able to couple five units in the automatic mode with two units meeting the cycle time spec of three minutes. The three devices that did not meet the spec of three minutes, took as long as four and a half minutes because of difficulties in achieving maximum responsivity. The misalignments could be due to the alignment routine for the production demo, which did not include the fine aligner. It wasn't included because the range of the fine aligner is only 25 microns and the photodiode illumination area is much larger than that. The epoxy dispenser had some trouble dispensing the correct amount of epoxy in the

center of the fiber at first. Once we determined the proper amount of epoxy, it seem to work adequately. It was also difficult to realign the epoxy tip after loading new epoxy. The source coupling module splice worked well, except at times when there was a broken fiber in the splice. In this instance there was no method to inform the operator of the problem until the complete pallet passed through, and all the fibers in the kit tray were damaged.

The kit tray loading procedure went very well. The loading of a photodiode package and a fiber was achieved in 2 minutes. This did not include the fiber preparation which was previously done off line. The loading process was to first place a photodiode package in the socket on the kit tay, and insert a fiber through the package fiber tube, until the fiber was approximately 0.5 mm from the photodiode chip. Then the kit tray was placed with the pallet on the conveyor and the process proceeded.

Production Demo Results

The 30 demo units were pigtailed by the AFPM and tested. The failures had either low responsivity or no responsivity. Low responsivity could occur because the AFPM did not realign the fiber after the epoxy was applied. Changing the process to realign after applying the epoxy would result in an improved yield. Realignment is necessary because the fiber could be seen moving during the epoxy dispensing. The units without responsivity were offset significantly in the 'X' plane, again due to not realigning after the epoxy was applied. It is also possible the units had low responsivity because the machine did not scan in the 'X' plane during coupling. This would require changing the program to allow for the 'X' scan. It was initially thought this would not be needed for photodiode coupling. After testing, the units were subjected to 10 temperature cycles of -40 to +85°C and retested again. The results show one unit dropping below spec and one unit increasing above spec. This could be due to the epoxy not curing properly or asymmetric dispersal of the epoxy.

Lessons Learned

All of the failures encountered can be expected with a new machine and a new process. With these results, one could determine areas for improvement. Ortel has recognized several areas for improvement. One improvement would be to eliminate the backlash in the coarse alignment stages. MIT has already found a solution to this and is currently correcting the Ortel stage. To improve the coupling routine, the range of the fine aligner would need to be increased to allow for the larger coupling area of a photodiode. Another area for improvement would be to enlarge the field of view for the vision system. We observed some units where the photodiode or the fiber was out of the field of view which caused the system to reject the unit. Currently, the photodiode and fiber have to be positioned accurately to place them in the field of view. This increases the set-up time. The epoxy dispensing unit could be improved by allowing three degrees of freedom for alignment after a new tip is inserted. An improved mounting fixture would also be helpful. Ortel has a design concept to improve the epoxy dispenser mounting and LLNL has improved the epoxy dispenser tip to allow the epoxy to flow symmetrically over the fiber. The camera mounting fixture needs to be improved to hold the camera more securely in place.

The software should be improved to allow for a graphical interface. The current software is difficult to operate and should include provisions for emergency stops.

Advantages

Ortel sees a lot of advantages in the AFPM, such as increased throughput when the machine is operating properly. The AFPM could increase photodiode coupling throughput by as much as 75% per coupling station. Also, the AFPM would allow an operator to attend to other tasks while the AFPM is operating and relieve an operator of the tedious pigtailing process.

The vision system was a crucial part of the machine and it performed accurately when all was working properly. With a vision system, the

process allows for fast coarse alignment, without the need for a coupling routine to perform a blind search for responsivity. The vision system performed its coarse alignment in 10 seconds or less during the production demo.

The AFPM could also be modified to couple lasers and is sufficiently versatile to accept different types of packages. It also could be adapted to allow some sort of laser welding or soldering instead of epoxy. Ortel sees a lot of potential with the AFPM once all the improvements or modifications are made.

Conclusion

The program was successful in proving the concept of the program objectives. Even though there were some initial problems, one would expect expect to encounter these type of problems with a new process and machine. With the improvements listed above, the AFPM has a lot of potential to serve as a valuable asset to an assembly process. It is possible for the AFPM to repay itself in approximately 6 months when it's meeting specifications. A manufacturing process will have to be modified to adapt to the AFPM as it currently is designed. It could, however, be modified to incorporate another manufacturing process such as laser welding, soldering, or another type of epoxy. The vision system allows an easy and precise method for coarse alignment of the fiber to an optical device. The AFPM can be an alternative method to a manual process for pigtailing either lasers or photodiodes.

APPENDIX B - NEWPORT REPORT

Newport

Final Report

Automated Fiber Pigtailing Machine Program

UTP 93-73 / BAA 93-22

Prepared by: Randy Heyler
Date: July 11, 1996
Revised September 12, 1996

I. Specification Review

The original AFPM specifications were conceived around basic functionality, performance, and cost targets that are still today reasonably valid. Several exceptions, however, should be pointed out:

Functionality: In order to address a large portion of the integrated optic market, a commercial AFPM must have "roll" alignment (θz) capability as an option. This was excluded from the project for cost and simplicity reasons, and because the target devices did not require it at this time. However, it is our experience that many commercial applications (such as WDM's and optical splitters) cannot be successfully pigtailed without automated "roll" alignment.

Performance: Our original "time per pigtail" targets did not take into account the part tray and machine loading/attending times, which have significant impact upon both factory throughput and total labor savings. Based on observations of the resulting tray loading process, targeted labor savings will not be realized until tray loading can be reasonable automated or significantly streamlined. When considering all time factors, the current "palletized" machine does not achieve significantly lower total labor-per-part times than "piece-by-piece" (manual load/unload) automation schemes (currently in the realm of 3 - 15 minutes per part). However, the palletized approach does improve overall machine utilization and reduce the operator skill level required.

Cost:. To achieve a commercial selling price of $100k, total burdened cost of the machine would have to be in the $40k range (for a 3-axis system). This would translate into a direct material cost of approximately $25k-$30k. Based upon the

current design single-unit material cost of $48.5k, this is unlikely to be met even with volume purchases.

The coarse-fine positioning system accounted for at least a 50% reduction in the cost of alignment stages when compared to commercially available high-performance production-qualified stages, reducing the overall cost by about $8,000 in a 3-axis system (Note: this assumes substantial cost reduction from volume purchases of the AFPM stages). This would correspond to about a $20k price reduction. However, there are other commercially available coarse-fine (stepper/piezo) mechanics which are more comparable to the performance of the AFPM stages, and would be more cost-competitive with the AFPM design. A basic cost comparison is presented in Exhibit 1.

The remainder of the AFPM was based mostly upon commercially available hardware, so it is assumed that only OEM-type volume discounts (typically about 20-30%) could be negotiated for further cost reduction.

It is our estimate that the current design would have (best-case) a final "burdened cost" of about $55k (including software - see Exhibit 2), and could be "productized" if sufficient demand existed to sell for about $140k (including parts trays and conveyors). As a reference, currently available 3-axis manual load/unload systems (with complete align/epoxy attach functionality and device tooling) retail for about $125k.

II. Performance Evaluations

Based on observations of the machine runs, the following comments/recommendations apply:

Parts and Tray Preparation: Still a large contributor to total cycle time. The tray loading time needs to be less than the pigtailing cycle time to maintain a one-to-one operator/machine ratio. In UTP's case, the tray loading was still exceeding the total projected pigtailing cycle time (~15 min. vs. ~ 10 min). For Ortel, the loading was much faster (~2 minutes) and met this critical objective. Although functional, the kit trays need a lot of refinement to make them easy and quick to load. The UTP tray also had problems with the repeatability and hold-down reliability of the chips - limiting their use in a production environment. Balancing robust strain relief of fiber while enabling the vacuum chucks to reliably grab the fibers also needs work. (playing with this was a source of most of the additional loading time). Fiber spools should be more temperature resistant to accommodate environmental testing and elevated-temperature curing processes, however this was not specified in the program.

Pigtailing Process - alignment, bonding: While I didn't witness vision-based alignments, the overall alignment process seemed to work fairly well on the UTP machine. The coupling of fibers into source/detectors operated nicely, and judging from test results the alignments were accurate. The epoxy dispensing worked OK, but was not a process that could be left unattended in my opinion. Some vision-based validation of epoxy dispensing is probably crucial for a robust process. Cleaning or replacement of epoxy tips and re-positioning of the tip in a calibrated location add some uncertainty and set-up time to the process.

The alignment for the Ortel system had substantial problems due to backlash of the coarse positioning stages. Fixes for this problem have been qualified on the UTP system but not yet tested on Ortel's machine. UTP overcame this initially by using a uni-directional alignment algorithm. (See comments on Motion Systems).

Operator Interface: While functional, the software interface does little to provide access to code and parameter adjustments, or to log operator and system activity/results (essential for process monitoring and control). Another major issue is the detection and control of "alarm" conditions, such as parts missing, alignment incomplete, no coupling achieved, etc. Failure detection and recovery algorithms needs to be thought-out and implemented.

These are crucial features in any commercial automation system. However, it is our opinion that the objectives of the program were "proof of principle" and not to design a commercial GUI engine for the system. Vendors will need to provide a commercial process automation software platform that can be utilized for this purpose.

Cycle Time and Throughput Analysis - TBD based on final tabulated results from UTP and Ortel. In general, the "align and bond" targets were met, but the overall cycle times (and potential labor savings objectives), when including part tray loading and machine monitoring, were not.

Machine Component Performance:

Motion Systems: Some trouble with linkage backlash in the C/F modules (evidently bushing and/or timing belt related) severely compromised system performance on the Ortel and LLNL machines. (I did not observe this at UTP as they modified the software to overcome this). This is the most critical component of the system, and needs to be reliable and repeatable. Camera, epoxy and conveyor motion systems were all adequate but a little "rough." Need to add focusing and manual "x-axis" adjustment for the camera system, and soften the pneumatic shuttle of the camera

Vision System, Couplers, etc.: Vision system lighting and contrast could be improved, but automated algorithms seem to work fairly well. On occasion, errors

are made in detecting the edge of the photodiode (Ortel), resulting in crashing the fiber.

The Norland couplers proved to be fairly consistent during the production runs, but occasionally the fiber would fracture and leave remnants within the splice. This could be a major reliability or maintenance issue for the machine in unattended operation.

Parts Handling: The conveyor system operated nicely, and the parts tray positional repeatability (less than 100 microns) was well within the vision system tolerance. This approach seemed simple and well implemented in general.

The fiber gripper scenario still needs some work, as the vacuum on occasion could not overcome the spring forces in the fibers, and there was no means to detect a "dropped fiber" during the process (other than process failure). The load-carrying capability, repeatability and robustness of the fiber grippers need substantial improvement to work in an unattended automation scenario.

IV. Commercialization Potential, Issues and Risks

The key issues with regard to commercialization focus upon system and component reliability. In an automation environment, the machine must be extremely fault-tolerant, have good "recovery" capability (since many OE devices are quite expensive), and perform reliably. Observed problems with C/F positioning, edge detection, epoxy dispensing/needle changing, fiber grippers and source coupling must be corrected and statistically tested before commercial systems could be sold. A potential customer will expect at least 80% up-time of the machine, and at least 80% first-pass throughput yield.

Potential for the machine is high on the basis of flexible accommodation of device types. However, as previously mentioned, "roll" (θz) alignment capability is a requirement for array and PM fiber applications and will be a required option.

The cycle-time and labor reduction potential of automating this process is huge, but only if device performance and yields can be maintained or improved. Potential system volume is difficult to predict due to the "chicken and egg" nature of the current market - with reduced costs, volume should soar. However, volumes will not increase until lower costs are TRULY realized (or somebody drives the price curve artificially to gain volume).

Device and attachment technology is also embryonic - many OE suppliers are veering away from adhesives to achieve longer life and better performance, and some devices (e.g. splitters) are still challenged by existing technologies (e.g. fused fiber splices). This adds to the unpredictability of system and device demand.

It is nonetheless still our feeling that the pursuit of automation for OE-specific packaging processes (e.g. fiber prep/handling, align-and-attach) is both necessary and the first priority in advancing deployment of OE devices for communications and sensing applications. Exhibit 3 presents some of the key milestones required to further refine the technology and successfully commercialize an AFPM in today's market.

V. Conclusions and Recommendations

I felt the group worked effectively overall, as manifested by the significant and important results gained from the program. In total, the project met and even exceeded my expectations in terms of the ability of industry and government to collaborate on a specific, focused program. While the resulting machine still requires a great deal of refinement to achieve "unattended" operation status, the feasibility of all essential processes within the targeted cycle time was demonstrated.

Division of design tasks among LLNL and MIT caused some unavoidable integration problems, which will always happen when design teams are not co-located. In general, however, the division of the tasks made sense as they for the most part gave each design team "ownership" over a complete function or process (such as C/F positioning, vision alignment). Local "ownership" of the two machines according to geography (MIT/UTP, LLNL/Ortel) also made sense.

Our recommendation for follow-on work should focus on more robust vision-related processing (for failure detection and recovery) and automation of the part preparation/tray loading process. These are the biggest bottlenecks to successful, unattended operation of a high-volume AFPM.

Newport is currently working towards refining some of the basic machine elements and preparing for eventual implementation on commercial systems. Key areas include high magnification imaging/image processing, epoxy and UV illumination positioning mechanisms, and overall system process automation software. We will attend the industry demonstration at LLNL to more concisely assess current interest to guide our development timetables.

Exhibit 1
Coarse-Fine Module Savings

	Prototype Cost (mat'l only)	Estimated Production Cost (Incl. assy+ovhd)	Estimated Production Price	Commercially Available Price[1]	Commercially Available Price[2]	Savings
3-axis C/F Module	$ 6,500	$ 5,500	$ 11,000	$ 29,000	$ 17,000	$5,000 - $18,000

Notes:

1. Base-case Newport PM500 Closed-loop DC Servo Stages
2. Base-case Melles-Griot PowerFlex/PowerBlock (motor/piezo hybrid)

Exhibit 2
Estimated System Costing/Pricing

	Prototype Mat'l	Prod'n Mat'l (-30%)	Prod'n Labor (100 hrs)	Mat'l/Labor Overhead	Burdened Cost	Software	System Price (60% gm)
Total System	$ 48,596	$ 34,017	$ 1,200	$ 9,903	$ 45,120	$ 10,000	$ 137,799

Exhibit 3

Commercialization Roadmap

Machine commercialization requires further development of the prototype platform to provide a robust, reliable platform for production environments. The roadmap to bring the AFPM to market consists of three distinct phases. The first two phases may be approached concurrently to some extent if resources permit.

Phase I: Mechanism and Process Refinement, Reliability Testing and Improvements

A. Positioning systems
B. Fiber Coupling
C. Vision and Alignment Algorithms
D. Epoxy delivery and UV Curing
E. Kit Trays, part fixturing

Outcome: Robust, production-qualified mechanism and process modules which can be adapted to different device types.

Phase II: Final System and Software Integration

A. Adaptation/conversion of base processes into a qualified automation software platform
B. Interlocking, Enclosure and Safety Feature Design
C. Mechanical Platform Refinement
D. Certification and Performance Testing
E. Beta Site Testing

Outcome: Completed system design qualified for release to production

Phase III: Production Implementation

A. Fabrication and Assembly Documentation, Vendor Selection

B. Pilot Manufacturing and Service Training

C. Sales Release

Outcome: Sales and service of AFPM systems to production installations

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